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THEORETICAL AND EXPERIMENTAL INVESTIGATION OF A FEEDER REFLECTOMETER

A. R. Vol'pert
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This paper deals with a theoretical and experimental investigation of the operation of a feeder reflectometer for remote measurement of the traveling-wave ratio in feeders. This ratio, which is apparently inversely proportional to the more commonly used standing-wave ratio (SWR), will hereafter be referred to as the TWR. Figures referred to are appended.

INTRODUCTION

In tuning antennas with feeder supply, the main problem is that of obtaining the highest possible TWR.

Existing methods of measuring the TWR are generally based on the distribution of current or voltage in the feeder. These methods are not completely satisfactory, since they involve many measurements at different points of the feeder and subsequent calculations. In the case of short feeders, of the order of a quarter wave length, for example, these methods are generally inapplicable.

Moreover, in operating tuned antennas it is important to maintain constant control over the operating conditions in the feeder, since a sharp reduction in the TWR may disturb transmission or, if the transmitter is sufficiently powerful, cause insulation breakdown, arc-overs, and other damaging effects.

Traveling waves are most simply controlled through the use of several instruments connected at different points of the feeder, which give, when properly spaced, identical readings only when traveling waves are present. But this method will give more or less accurate results only when more than three instruments are used, and moreover, it does not permit any quantitative estimate of possible variations in the TWR.

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Therefore, antenna engineering urgently needs an instrument which will, when connected with any section of a feeder, give readings, directly or indirectly of the actual TWR in the feeder. Such an instrument would make it possible to tune the antenna from its readings and to follow conditions in the feeder during operation.

To control operating conditions in a feeder, A. A. Pistol'kors (Certificate of Authorship No 53838, 22 November 1939), suggested a traveling-wave indicator in the form of a feeder section running parallel to the main feeder and loaded at the end opposite the transmitter by an instrument which measures the hf current or voltage and at the other end by an effective resistance of a definite value. It has been theoretically shown that this instrument will read zero when traveling waves are present.

Despite the above advantages, this device is unsatisfactory because the instrument cannot be calibrated in TWR units, since its readings depend on the power in the main feeder. Therefore, Pistol'kors' device does not permit one to estimate how far the operating conditions in the feeder differ from perfect traveling-wave conditions.

M. S. Neyman has proposed two variations of this device, which do not differ in principle (Claim No P-54, 15 April 1940), to make the instrument readings independent of the power in the feeder.

In the first variation, two feeder sections are extended parallel to the main feeder. In the first section, the instrument is connected on the antenna side and the effective resistance on the transmitter side. In the second section, the instrument is connected on the transmitter side and the resistance on the antenna side. Both instruments act as hf rectifiers and the direct currents obtained are fed to a current ratiometer. The current ratio does not depend on the power, but is determined only by the TWR in the main feeder. Hence, the ratiometer can be calibrated directly in TWR units.

The second variation has only one measuring feeder section with equal effective resistances and hf rectifiers connected to both ends. As in the first case, the rectified currents are fed to a ratiometer. It is obvious that this variation is more satisfactory than the first, from the design standpoint. Its use in a two-wire and coaxial feeder is shown in Figures 1 and 2.

The second variation is a convenient instrument for tuning the antenna, and controlling operating conditions in the feeder from the TWR readings. Tuning and control can be effected remotely, since the ratiometer can be placed at any desired distance from the measuring feeder section.

The author made a theoretical and experimental study of the practical application of the device proposed by M. S. Neyman. This study revealed the following additional properties of the device: the ratio of the currents fed to the ratiometer, for a given value of the effective resistance, does not depend on the wave length. This feature makes the device suitable for use over a band of frequencies. Moreover, the current ratio is exactly equal to the reflection coefficient in the main feeder. Since the reflection coefficient is directly related to the TWR, the measuring device does not require special calibration. This fact prompted us to call the device a feeder reflectometer.

Furthermore, the theory underlying the reflectometer showed that its readings are also independent of the point of coupling with the main feeder. The present work on this subject was carried out in late 1940, but publication was delayed by the war. The operating principle of the reflectometer was published jointly by M. S. Neyman and A. A. Pistol'kors [1].

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THEORETICAL SECTION

Basic Relations

We consider a system composed of two parallel lines without distributed losses, with electric and magnetic coupling, and a generator of alternating emf connected in the primary line (Figure 3). We shall take the end of the secondary line opposite the generator as the origin of the coordinate system.

We call the potential difference at the ends of lines I and II in the section $x = 0$ U_I and U_{II}, respectively, and the end currents, I_I and I_{II}. We can then write the equations for voltages and currents in the section $0 \leqslant x \leqslant \ell$ as follows [2]:

$$U_1 = U_I \cos mx + i\,(I_I \rho_{a1} + I_{II} \rho_c) \sin mx \tag{1}$$

$$I_1 = I_I \cos mx + i \left(\frac{U_I}{\rho_1} - \frac{U_{II}}{\rho_{12}} \right) \sin x \tag{2}$$

$$U_2 = U_{II} \cos mx + i\,(I_{II} \rho_{a2} + I_I \rho_c) \sin mx \tag{3}$$

$$I_2 = I_{II} \cos mx + i \left(\frac{U_{II}}{\rho_2} - \frac{U_I}{\rho_{12}} \right) \sin mx \tag{4}$$

Here U_1, U_2, I_1, and I_2 are the voltages and currents in the primary and secondary lines; $m = \frac{2\pi}{\lambda}$; ρ_{a1} is the characteristic impedance of the primary line in the absence of the secondary line; ρ_{a2}, the characteristic impedance of the secondary line in the absence of the primary line; ρ_1 and ρ_2 are the characteristic impedances of lines I and II, taking into account their influence on each other; ρ_{12} is the characteristic mutual impedance of lines I and II, and ρ_c is the characteristic coupling impedance.

The values of the characteristic impedances are determined from the following formulas:

$$\begin{aligned}
\rho_{a1} &= 120\, d_{11} \\
\rho_{a2} &= 120\, d_{22} \\
\rho_1 &= 120 \frac{d_{11} d_{22} - d_{12}^2}{d_{22}} \\
\rho_2 &= 120 \frac{d_{11} d_{22} - d_{12}^2}{d_{11}} \\
\rho_{12} &= 120 \frac{d_{11} d_{22} - d_{12}^2}{d_{12}} \\
\rho_c &= 120\, d_{12}
\end{aligned} \tag{5}$$

The values of d_{11}, d_{22}, and d_{12}, which depend on the size and geometrical arrangement of lines I and II, will have the following values for the case of two-wire lines [3]:

$$d_{11} = \ln \frac{D_{11}}{a_{11}}, \quad d_{22} = \ln \frac{D_{22}}{a_{22}} \text{ and } d_{12} = \ln \frac{D_{12}}{a_{12}} \tag{6}$$

All symbols used here are explained by Figure 4. For a coaxial system (Figure 5), these will have the following form:

$$d_{11} = \frac{1}{2} \ln \frac{R}{r_1}, \; d_{22} = \frac{1}{2} \ln \frac{R^2 - g^2}{r_2 R} \text{ and } d_{12} = \frac{1}{2} \ln \frac{R}{g}, \qquad (7)$$

From formulas (5), we obtain a simple equation relating the following separate characteristic impedances:

$$\frac{\rho_{a1}\,\rho_2}{\rho_{12}\,\rho_c} = 1 \qquad (8)$$

Moreover, in most practical cases the difference between some of the characteristic impedances is very small. For example:

$$\rho_{a1} \approx \rho_1 \text{ and } \rho_{a2} \approx \rho_2 \qquad (9)$$

The equations are correct to a fraction of a percent for two-wire lines and to a few percents for coaxial systems.

We now derive expressions for currents in the secondary line in the sections $x = 0$ and $x = \ell$ as a function of the current in the primary line. Letting Z_1 be the input impedance of the primary line in the section $x = 0$ and Z_2 and Z_3 (Figure 6), be the impedances at the ends of the secondary line, we have:

$$U_I = I_I Z_1, \; U_{II} = I_{II} Z_2 \text{ and } U_{2\ell} = -I_{2\ell} Z_3.$$

The minus sign in the last equation arises because the current $I_{2\ell}$ in the impedance Z_3 is flowing in the opposite direction to the current I_{II}.

We use the last equations and formulas (1)-(4) to obtain:

$$I_{II} = -i I_I \frac{\left(\rho_c - \frac{Z_1 Z_3}{\rho_{12}}\right) \sin m\ell}{(Z_2 + Z_3)\cos m\ell + i\left(\frac{Z_2 Z_3}{\rho_2} + \rho_{a2}\right)\sin m\ell}, \qquad (10)$$

$$I_{2\ell} = -i I_I \frac{\left(\rho_c + \frac{Z_1 Z_2}{\rho_{12}}\right)\cos m\ell + i\left(Z_1 \frac{\rho_{a2}}{\rho_{a12}} + Z_2 \frac{\rho_c}{\rho_2}\right)\sin m\ell}{(Z_2 + Z_3)\cos m\ell + i\left(\frac{(Z_2 Z_3)}{\rho_2} + \rho_{a2}\right)\sin m\ell} \sin m\ell. \qquad (11)$$

We recall that the current I_{II} (Figure 6), corresponds to the end of the secondary line opposite the transmitter.

Theory of the Reflectometer

Expressions (10) and (11) are the basis for the derivation of all relationships characterizing the secondary line as a unit for measuring the TWR in the primary line.

It follows from expression (10) that the current I_{II} flowing through the impedance Z_2 will be zero if the following condition holds:

$$\rho_c - \frac{Z_1 Z_3}{\rho_{12}} = 0.$$

By changing this condition to the following form:

$$1-\frac{Z_1 Z_3}{\rho_{a1}\rho_2}\,\frac{\rho_{a1}\rho_2}{\rho_c\,\rho_{12}}=0$$

and using equation (8), we obtain:

$$1-\frac{Z_1 Z_3}{\rho_{a1}\rho_2}=0 \qquad (12)$$

It is obvious that condition (12) will occur for various values of Z_1 and Z_3. But if we set $Z_3 = \rho_2$, the current I_{II} will be zero only when $Z_1 = \rho_{a1}$, that is, only when there are traveling waves in the feeder. This last statement is the basis of the reflectometer.

Since the value of the impedance Z_2 is immaterial in condition (12), let us assume that $Z_2 = Z_3 = \rho_2$. Then using equations (8) and (9), we can write (10) and (11) in the following form:

$$I' = \left| I_I\left(1-\frac{Z_1}{\rho_{a1}}\right)\sin ml \right| \frac{\rho_c}{2\rho_2}, \qquad (13)$$

$$I'' = \left| I_I\left(1+\frac{Z_1}{\rho_{a1}}\right)\sin ml \right| \frac{\rho_c}{2\rho_2}, \qquad (14)$$

where we set $I' = \left| I_{II} \right|$ and $I'' = \left| I_{2l} \right|$.

From formulas (13) and (14), we obtain as the ratio of the currents at the ends of the reflectometer:

$$\frac{I'}{I''} = \left| \frac{\rho_{a1}-Z_1}{\rho_{a1}+Z_1} \right|. \qquad (15)$$

The expression thus obtained is simply the reflection coefficient in the main feeder [4], which is related to the TWR k by the equation:

$$k=\frac{1-p}{1+p}, \qquad (16)$$

where p is the absolute value of the reflection coefficient.

Hence, we conclude that the current I' is caused only by reflected waves in the feeder, while the current I" is caused only by direct waves, since by definition:

$$p=\left|\frac{U_{ref}}{U_{dir}}\right| = \left|\frac{I_{ref}}{I_{dir}}\right|.$$

In fact, if we write the formulas (13) and (14) in the form:

$$I' = \left| (I_I\rho_{a1} - U_I)\sin ml \right| \frac{\rho_c}{2\rho_{a1}\rho_2},$$

$$I'' = \left| (I_I\rho_{a1} + U_I)\sin ml \right| \frac{\rho_c}{2\rho_{a1}\rho_2}$$

and if we then make use of the basic principles of the theory of lines [4]:

$$U_I = U_{dir} + U_{ref} \quad \text{and} \quad I_I\,\rho_{a1} = U_{dir} - U_{ref}$$

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we obtain the following:

$$I' = \left| I_{ref} \sin ml \right| \frac{\rho_c}{\rho_2}, \tag{17}$$

$$I'' = \left| I_{dir} \sin ml \right| \frac{\rho_c}{\rho_2}. \tag{18}$$

The physical interpretation of these equations is given in [1]. [17].

Thus the current I" always differs from zero while the current I', as shown in (18), becomes zero with a traveling wave present only when $I_{ref} = 0$. Moreover, for a standing wave I' = I", since here $|I_{ref}| = |I_{dir}|$.

Two very important consequences, besides that of independence of power in the feeder, result from (15). First, the ratio of the currents does not depend on the point at which the reflectometer is coupled with the feeder, since the reflection coefficient in all sections of a uniform line is a constant, and, secondly, the current ratio does not depend on the wave length of the oscillator exciting the feeder.

We also see from formulas (17) and (18) that not only is the current ratio independent of the point at which the reflectometer and feeder are coupled, but that the currents I' and I" are likewise independent, since the amplitudes of the currents I_{ref} and I_{dir} are constant along the feeder.

It is essential to know the limits within which I' and I" vary with variation in the power and TWR in the feeder to select instruments to measure the current or voltage at the ends of the reflectometer. Since the values of I' and I" do not depend on the point of connection, we will assume, to simplify the following computations, that the end of the reflectometer with the current I' is opposite a current loop in the feeder. We shall then have:

$$I_I = \sqrt{\frac{P}{\rho_{a1}}} \text{ and } \frac{Z_1}{\rho_{a1}} = k,$$

where P is the active power in the feeder.

Substituting these expressions in formulas (13) and (14), we obtain:

$$I' = \sqrt{\frac{P}{\rho_{a1}}} \frac{1-k}{\sqrt{k}} \frac{\rho_c}{2\rho_2} \left| \sin ml \right|, \tag{19}$$

$$I'' = \sqrt{\frac{P}{\rho_{a1}}} \frac{1+k}{\sqrt{k}} \frac{\rho_c}{2\rho_2} \left| \sin ml \right|. \tag{20}$$

Formulas (19) and (20) enable us to calculate the possible values of the currents I' and I" for various feeder and reflectometer parameters. For constant power P, the maximum variation of the currents I' and I" depend on coefficients which are dependent on k. It is evident from formulas (19) and (20) that the reflectometer can also be used to measure power in the feeder (B. G. Strausov [8] has worked on this problem).

We should bear in mind that when $k \to 0$, formulas (19) and (20) are not applicable in the form cited because here P also approaches 0. In this case, formulas (19) and (20) can be written thus:

$$I' = \frac{U_{max}}{\rho_{a1}} (1-k) \frac{\rho_c}{2\rho_2} \left| \sin ml \right|,$$

$$I'' = \frac{U_{max}}{\rho_{a1}} (1+k) \frac{\rho_c}{2\rho_2} \left| \sin ml \right|,$$

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where U_{max} is the voltage at a feeder loop. These formulas are obtained from the expression: $P = \frac{U^2_{max}}{\rho_{a1}} k$.

Influence of the Value of the Impedance Z_3

All the above results hold only for the case where ρ_2 is equal to the impedance Z_3. Since the impedance in practice may not be exactly the value desired, it is important to determine the extent to which an inaccurate value of Z_3 may affect the reflectometer readings.

Let us assume, as we did in deriving formulas (13) and (14), that $Z_2 = Z_3$ and also that $Z_3 = R_2$, where $R_2 = \rho_2 + \Delta\rho_2$. From (10) and (11), taking formulas (8) and (9) into consideration, the ratio of the currents will be:

$$\frac{I'}{I''} = \left| \frac{1 - \frac{Z_1}{\rho_{a1}} \frac{R_2}{\rho_2}}{\left(1 + \frac{Z_1}{\rho_{a1}} \frac{R_2}{\rho_2}\right) \cos ml + i \left(\frac{R_2}{\rho_2} + \frac{Z_1}{\rho_{a1}}\right) \sin ml} \right|. \tag{21}$$

First let us consider the case of a traveling wave in the feeder ($Z_1 = \rho_{a1}$). Then expression (21) will reduce to the following:

$$\frac{I'}{I''} = \left| \frac{\rho_2 - R_2}{\rho_2 + R_2} \right|. \tag{22}$$

In general, the ratio of the currents is now no longer zero, but may take any value between 0 and 1, **depending** on the value of R_2.

To estimate the error introduced by a resistance R_2 different from ρ_2, it is convenient to express R_2 in terms of $\Delta\rho_2$. Now, from formula (22), we obtain:

$$\frac{I'}{I''} = \left| \frac{\frac{\Delta\rho_2}{\rho_2}}{2 + \frac{\Delta\rho_2}{\rho_2}} \right|.$$

Hence, it is evident that the error in the readings for a traveling wave is only approximately half the relative error in the value of the impedance, a very fortunate characteristic of the device.

In the general case when $Z_1 \neq \rho_{a1}$, expression (21) shows first that the ratio of currents depends on the length of the reflectometer. However, if the length of the reflectometer is small in comparison with the wave length, we can assume with sufficient accuracy that $\sin ml \approx 0$ and $\cos ml \approx 1$.

We can now obtain the following more graphic expression:

$$\frac{I'}{I''} = \left| \frac{\rho_{a1}\rho_2 - Z_1 R_2}{\rho_{a1}\rho_2 + Z_1 R_2} \right|. \tag{23}$$

If Z_1 is an active value not equal to ρ_{a1} ($Z_1 = R_1$), that is, if I_1 corresponds to a node or loop in the feeder, false zero values of the current I' may appear when k is not unity. As is clear from (23), this will occur when:

$$\frac{R_1}{\rho_{a1}} = \frac{\rho_2}{R_2},$$

This corresponds to a TWR equal to $\frac{R_1}{\rho_{a1}}$ or $\frac{\rho_{a1}}{R_1}$. This fact must be kept in mind in experimental selections of the resistance R_2. Figure 7 shows the dependency of the current ratio on the quantity $\frac{R_2}{\rho_2}$ for various values of $\frac{R_1}{\rho_{a1}}$. When Z_1 is complex ($Z_1 = R_1 + iX_1$), false zeros do not occur but minimum values of the ratio $\frac{I'}{I''}$ may be obtained. When $R_2 = \rho_2$, the minimum value will correspond to the actual value of k. Otherwise, the magnitude and position of the minimum will depend on R_1, X_1, and R_2.

Influence of the Reflectometer on the Feeder

We will now determine the extent to which the reflectometer influences the feeder. This problem is of great practical importance since the reflectometer measures the reflection coefficient in the section x = 0, that is, only in the section between the feeder load and the beginning of the reflectometer. If the influence of the reflectometer is noticeable, it will reduce the TWR in the part between the section $x = \ell$ and the oscillator; consequently, the reflectometer readings will not indicate the actual operating conditions in the feeder.

Comparison of the input impedance of the feeder in front of the reflectometer in the section x = 0, and behind it in the section $x = \ell$ can be used as a criterion of the influence of the reflectometer. We examine the influence of the reflectometer under the condition that a traveling wave is present in the feeder. From expressions (1) and (2), we have in the section $x = \ell$

$$Z_{1\ell} = \frac{U_I \cos m\ell + i(I_I \rho_{a1} + I_{II}\rho_2)\sin m\ell}{I_I \cos m\ell + i\left(\frac{U_I}{\rho_1} - \frac{U_{II}}{\rho_2}\right)\sin m\ell}.$$

For a traveling wave, $I_I \rho_{a1} = U_I$, and moreover, $I_{II} = U_{II} = 0$.

We now obtain from the last expression:

$$|Z_{1\ell}| = \frac{\rho_{a1}}{\sqrt{\cos^2 m\ell + \left(\frac{\rho_{a1}}{\rho_1}\right)^2 \sin^2 m\ell}}.$$

Since the length of the reflectometer is ordinarily very small in comparison with the wave length, for $Z_{1\ell}$ we obtain, approximately:

$$|Z_{1\ell}| \approx \rho_{a1}\left[1 - \frac{m^2\ell^2}{2}\left(\frac{\rho_{a1}^2}{\rho_1^2} - 1\right)\right].$$

Hence, for a traveling wave, the influence of the reflectometer is determined, on the one hand, by its length and, on the other hand, by the amount of coupling (the latter determines the degree to which the ratio $\frac{\rho_{a1}}{\rho_1}$ differs from unity). In practice, the ratio $\frac{\rho_{a1}}{\rho_1}$ differs only very [redacted] unity, so that $|Z_{1\ell}| \approx \rho_{a1}$. Consequently, we can disregard the influence of the reflectometer.

EXPERIMENTAL SECTION

Description of the Device

The reflectometer was studied experimentally using wave lengths from 50 to 100 m. The feeder used in the experiments was a square wooden box about 21 m long, faced with sheet aluminum on the inside. An aluminum pipe passed through the center of the box. There was a circuit with variable parameters at the end of the feeder for tuning to traveling waves, which made it possible to regulate the TWR in the feeder within wide limits. A general view of the feeder is given in Figures 8 and 9.

The reflectometer was placed at the beginning of the feeder (near the oscillator), in a special recession in the side wall. The reflectometer line was 3 m long. The cross-sectional dimensions of the feeder in the reflectometer section are shown in Figure 10.

Holders were installed at both ends of the reflectometer to connect in Kaminskiy-type resistances. The resistances were connected between the ends of the reflectometer and the shielded side wall. Type VKS-7 vacuum tube voltmeters were connected in parallel with the resistances to measure the hf voltage.

Voltmeters of this type consist of a conventional diode rectifier using a Type 955 acorn tube and a dc amplifier. The diode part is mounted in a probe, connected with the amplifier by a flexible shielded hose. This makes such voltmeters very convenient, since the probe can be mounted in the feeder itself.

The legs of specially built ratiometers were connected with the amplifiers of the vacuum-tube voltmeters instead of galvanometers. These legs had the same resistance ($\sim 500\,\Omega$) as galvanometers. This substitution was possible because of the scale linearity of the VKS-7 vacuum-tube voltmeter. Since such ratiometers are comparatively rare in radio engineering practice, we will briefly describe their principle of operation.

A diagram of the ratiometer is shown in Figure 11. The deflecting coil K_1 covers the whole core and moves like any moving-coil instrument in a uniform magnetic field. The second "fixed" coil K_2 covers only half of the core and makes a definite angle with the coil K_1.

The control coil K_2 is set so that when current flows through it alone, its magnetic axis coincides with the direction of the magnet's flux. If the form of the pole pieces is properly selected, the position of K_2 shown in Figure 11 will satisfy this condition. If this coil is moved to the right or left by an external force, it will always try to return to the indicated zero position. Thus, the coil K_2 functions as an "electrical spring." The deflection torque is produced by the coil K_1, which corresponds to the moving coil in a conventional meter.

The current is supplied to coil K_1 from the end of the reflectometer opposite the oscillator and to coil K_2 from the other end. When there is a traveling wave in the feeder, the current I' through the coil K_1 is zero. Hence, for a traveling wave the ratiometer gives a zero reading regardless of the current I" flowing through coil K_2, which always differs from zero [see formulas (17) and (18)]. When a reflected wave is present, the current I' through coil K_1 produces a deflection torque and the ratiometer will read the ratio $\frac{I'}{I''}$ of the currents flowing through coils K_1 and K_2.

In our experiments, the vacuum-tube voltmeters were placed right next to the feeder in shielded boxes connected with the feeder shield by a pipe (Figures 8 and 9). A cable passing through the pipe connected the probe with the amplifier. The probe itself was connected directly to the Kaminskiy resistors inside the feeder.

In the box, a lead-covered cable passed from each voltmeter to the ratiometer. The cable sheath was connected to the shield. The ground terminals of the voltmeters were also connected with the shield. These measures, taken to shield the voltmeters, were absolutely necessary in order to eliminate distortion of the readings by hf induction.

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Hf induction had a double effect as applied to voltmeters of the VKS-7 type. For example, induction in the conductors leading to the ratiometer tended, as a rule, to reduce the readings of the voltmeter so much that the pointers of the instruments returned to the zero position. Induction in the other compo-nents of the voltmeter, on the other hand, sometimes increased the readings. Com-plete shielding of all measuring equipment eliminated these effects.

Experimental Results

In determining characteristic impedances, we assumed that the cross-section of the feeder shield was circular (shown by the dotted line in Figure 10), and used formulas (5) and (7) for coaxial systems. The characteristic impedances thus obtained were:

$$\rho_{a1} = 89\,\Omega, \qquad \rho_1 = 86\,\Omega,$$

$$\rho_{a2} = 189\,\Omega, \qquad \rho_2 = 183\,\Omega,$$

$$\rho_{12} = 710\,\Omega, \qquad \rho_c = 23\,\Omega.$$

Obviously, these values are somewhat high since the shield was actually closer to the feeder pipe than the radius of the circle used in the calculations.

To estimate the error introduced by this assumption, the characteristic im-pedance ρ_{a1} of the feeder was calculated from the quite accurate formula which Ya. N. Fel'd [6] derived for feeders with square shields:

$$\rho_{a1} = 60 \ln \frac{\tanh\frac{\pi}{2}}{\tanh\frac{\pi r}{2a}},$$

where a is the side of the shield and r is the radius of the central pipe. For the dimensions shown in Figure 10, we found that $\rho_{a1} = 76\,\Omega$. Comparison of this value with the value obtained above shows that the error is approximately 15%.

The characteristic impedance ρ_2, with consideration for the effect of the feeder, was not known accurately, and this made it necessary to try experimental load resistances R_2.

The resistances R_2 are most easily determined for a TWR in the feeder of unity. Then a zero value for the current I' in the reflectometer would correspond to the required value of R_2, which can be found from paragraph 2 of the theoretical section.

We selected the resistances R_2 for a TWR of approximately 0.9 ($\lambda = 75$ m). We made a preliminary test to make sure that the cross section of the end of the re-flectometer opposite the oscillator did not coincide with a voltage node or loop in the feeder. Otherwise, a false zero value (see paragraph 3 of the theoretical section) might be obtained.

Furthermore, we had to make sure that the ratio $\frac{I'}{I''}$ actually was very close to a minimum when R_2 was equal to ρ_2. As shown in paragraph 3 (theoretical sec-tion), if the length of the line is small compared to the wave length:

$$\frac{I'}{I''} = \left| \frac{\rho_{a1}\rho_2 - Z_1 R_2}{\rho_{a1}\rho_2 + Z_1 R_2} \right|. \qquad (23)$$

If we introduce the symbols

$$\frac{R_1}{\rho_{a1}} = A, \quad \frac{X}{\rho_{a1}} = B \text{ and } \gamma = \frac{R_2}{\rho_2}$$

expression (23) can be written in the form:

$$\frac{I'}{I''} = \sqrt{\frac{(1-\gamma A)^2 + \gamma^2 B^2}{(1+\gamma A)^2 + \gamma^2 B^2}}. \qquad (24)$$

Whence it follows that the position of a minimum $\frac{I'}{I''}$ depends on a value of γ, determined from the following equation:

$$\gamma^2(1+B^2)-\gamma(1-A)-1=0. \qquad (25)$$

For a TWR of about 0.9 and $X_1 \neq 0$ (since the position of the reflectometer does not coincide with a node or loop in the feeder), it will be sufficiently accurate to consider that A = 1, and that the value k = 0.9 depends only on the value of B, which here must be about 0.1.

Then we obtain from formula (25):

$$\gamma=\frac{1}{\sqrt{1+B^2}}$$

or, since B^2 is very small compared with unity,

$$\gamma=1.$$

Thus, in the case under consideration, the position of minimum $\frac{I'}{I''}$ corresponds very closely to a value of R_2 equal to ρ_2.

Figure 12 shows the ratio $\frac{I'}{I''}$ as a function of the resistance R_2. From the curve, we see that the optimum value of R_2 is 170 Ω. The approximate value for ρ_2 in paragraph 2 of the experimental section was 183 Ω.

Using the value for ρ_2 thus found, in Figure 13 experimental points are drawn as a function of the ratio $\gamma=\frac{R_2}{\rho_2}$. The dotted line is the theoretical curve calculated from formula (24), assuming that A = 1 and B = 0.1. The experimental points agree very well with the theoretical curve. This confirms the reflectometer's principle of operation and the practical applicability of the formulas used in the calculations.

For the value of the resistance R_2 selected, a comparison was made between the reflectometer readings and TWR values found by the usual method, i.e., by curves of the voltage distribution along the feeder. The comparison was made for wave lengths from 50 to 100 m. The corresponding graphs are shown in Figure 14. The TWR values measured by the conventional method (k_{meas}), are plotted on the abscissa, while the values corresponding to the reflectometer readings (k_{ref}), are plotted on the ordinates. Both methods give essentially the same result.

Further experiments clarified the influence of irregularities in the reflectometer. For this purpose, local irregularities were artificially produced by means of a copper pin 60 mm long and 10 mm wide. The pin was installed in different positions at various points of the reflectometer. The experiments showed that the pin had virtually no effect on the readings.

Since the effect of the pin must be stronger than that of the supporting insulators and since the pin was considerably larger than any possible irregularities, the experiments proved that the conventional support methods and various irregularities cannot introduce any appreciable error into the reflectometer readings.

We should like to emphasize that the reflectometer measurements are very reliable and can be reproduced. Our study, therefore, fully confirmed the feasibility and practical advantage of using the reflectometer as an instrument for remote measurement of the TWR.

In conclusion, the author takes this opportunity to thank Professor M. S. Neyman for his assistance in this work.

[An appendix (5 text pages), showing the derivation of the equations for the characteristic impedances in a coaxial system, is omitted here.]

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BIBLIOGRAPHY

1. A. A. Pistol'kors and M. S. Neyman, "Device for Direct Measurement of the Traveling Wave Ration in Feeders", Elektrosvyaz', No 4, 1941

2. A. A. Pistol'kors, "Two-Wire Lines With Distributed Coupling", Nauchno-tekhnicheskiy sbornik po elektrosvyazi, No 1 (17), 1937

3. A. A. Pistol'kors, "Theory of Unsymmetrical Two-Wire Lines" Nauchnotekh-nicheskiy sbornik po elektrosvyazi, No 16, 1937

4. M. S. Neyman, "Transmitting Antennas," ONTI, p 44, 1934

5. Entsiklopediya tekhnicheskikh izmereniy, Vol 6, p 186, 1936

6. Ya. N. Fel'd, "Theory of Feeders With Rectangular Shielding," Elektrosvyaz', No 4, 1938

7. K. A. Krug, "Principles of Electrical Engineering," GNTI, Vol I, p 76, 1931

8. B. G. Strausov, "Device for Controlling the Power of Transmitters in Short-Wave Stations," Candidate's Dissertation, MIIS, 1946

[Figures 1-14 follow.]

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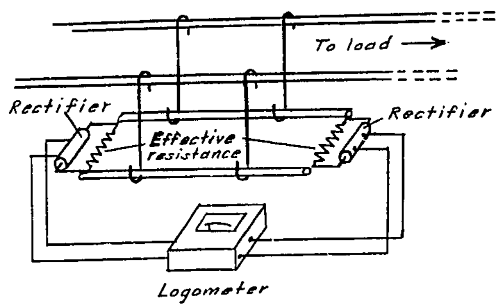

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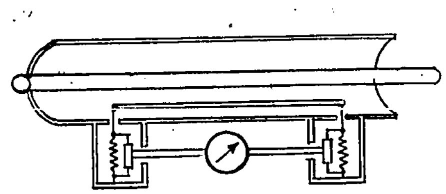

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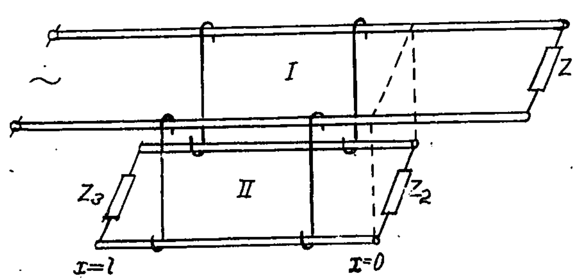

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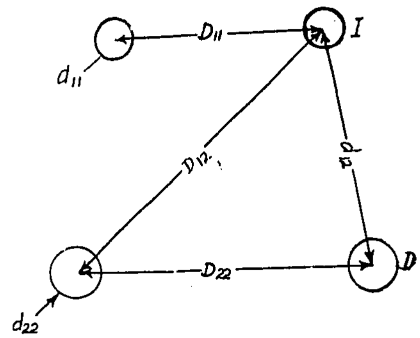

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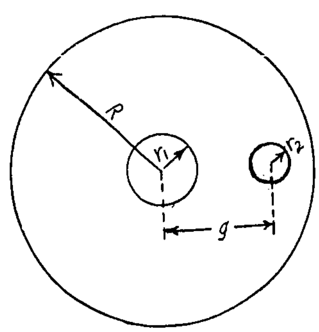

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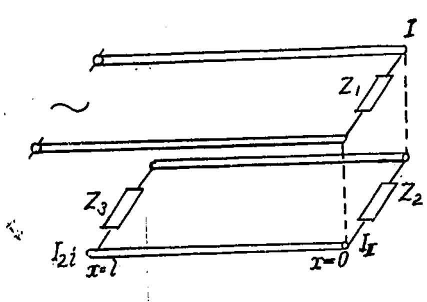

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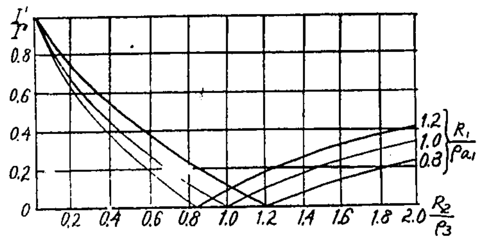

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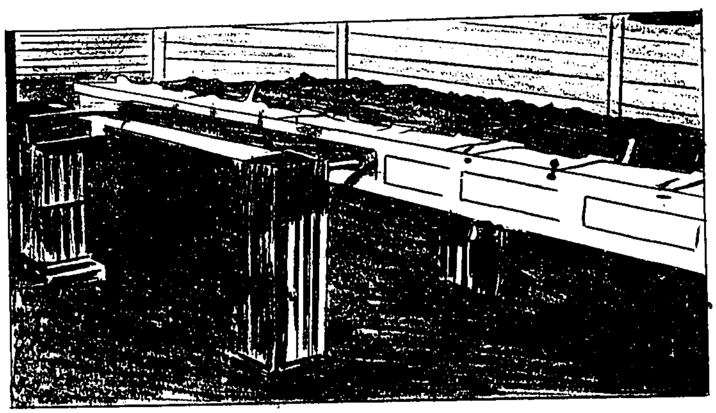

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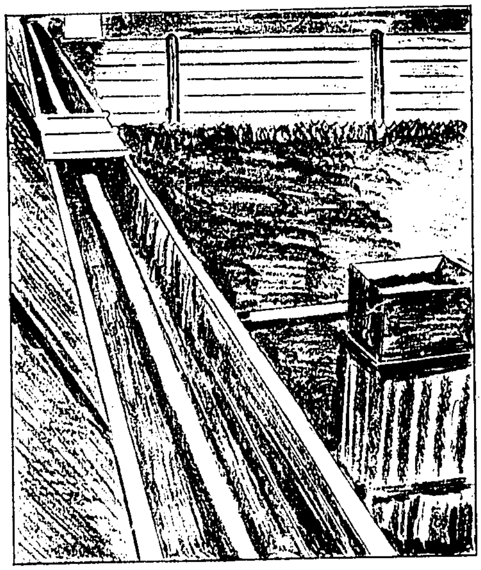

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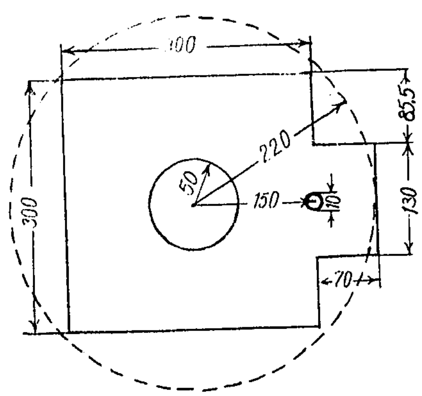

Figure 10.

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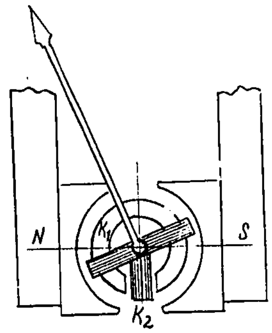

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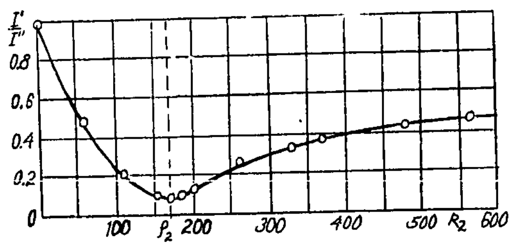

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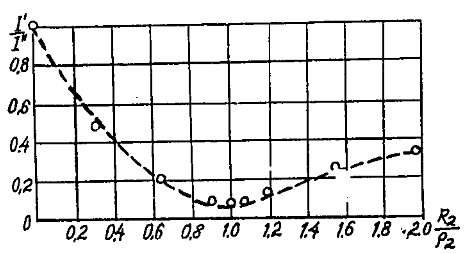

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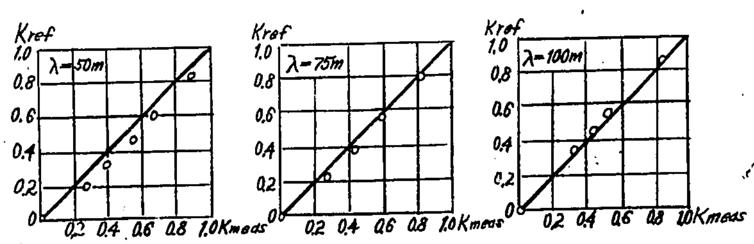

Figure 14.

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